UNIVERSITY AT ALBANY
State University of New York

Extreme Ultraviolet Phase Contrast Imaging

Gregory Denbeaux[1], Rashi Garg[1], Andy Aquila[2], Anton Barty[3], Kenneth Goldberg[2], Eric Gullikson[2], Yanwei Liu[2], Obert Wood[4]

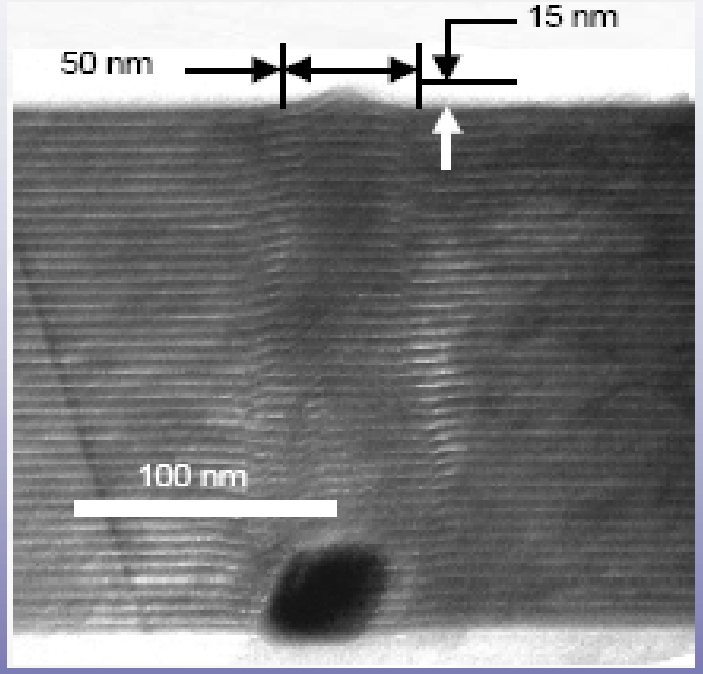
[1]College of Nanoscale Science and Engineering, University at Albany, Albany, NY
[2]Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
[3]Lawrence Livermore National Laboratory, P.O. Box 808, Livermore CA 94550
[4]SEMATECH, 255 Fuller Road, Suite 309, Albany, NY 12203

Outline

- Motivation – high resolution phase contrast imaging
- Approach
  - **High resolution zone plate optics with Zernike Phase Contrast**
- Experimental design
- First imaging results

EUV Phase Defects

- Pits or bumps under the Mo/Si multilayer used for the masks in EUV lithography will cause a local phase shift in the reflected radiation
- It is important to find the phase defects and measure the phase shift to determine the effect of the defect on the image formation and to work toward remediation if necessary
- A bump or pit of 2 nm at the surface of the Mo/Si multilayer may be printable



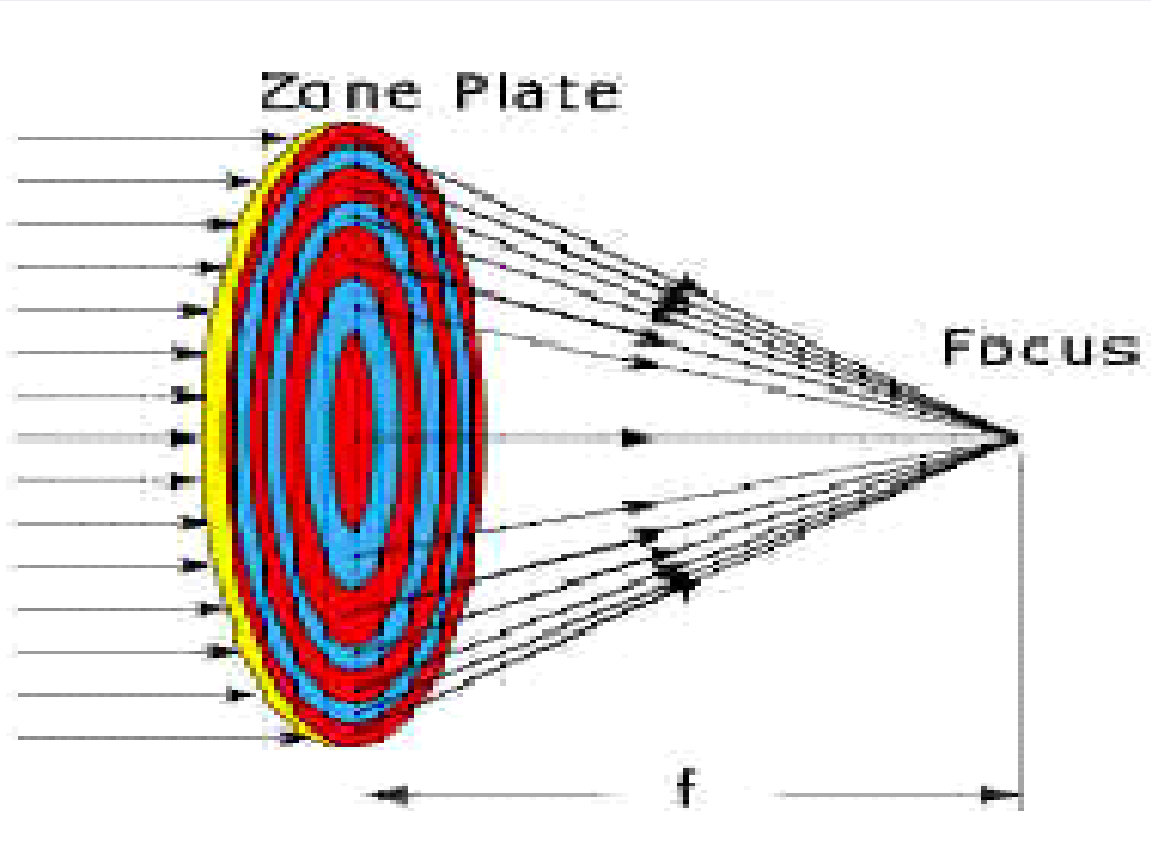
P.B. Mirkarimi et al, SPIE Microlithography March 2005

Phase contrast imaging can determine the phase shift and reflectivity change of defects with high resolution to help in the understanding of the cause and possible remediation

Phase Contrast

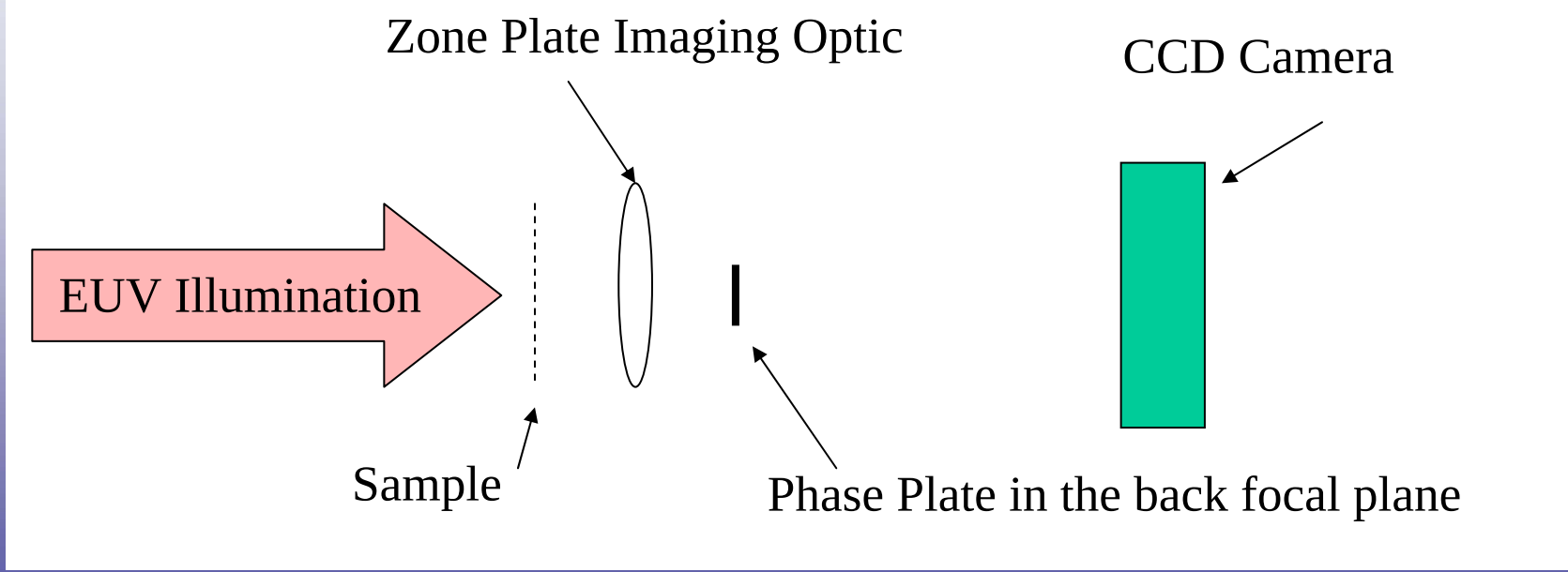
- By aligning a phase disk in the back focal plane of the zone plate imaging optic, Zernike phase contrast can be employed
- This phase contrast mode will also provide sub-nm measurements of the phase shift from phase defects
- Coupled with the 30 nm spatial resolution zone plate optics for imaging, this technique will provide the accurate maps of the phase shift across phase defects to better understand the causes of the defects, learn which are relevant to printing in EUV lithography, and to work toward repair strategies for the defects

Zone Plates – High resolution optics for short wavelength radiation

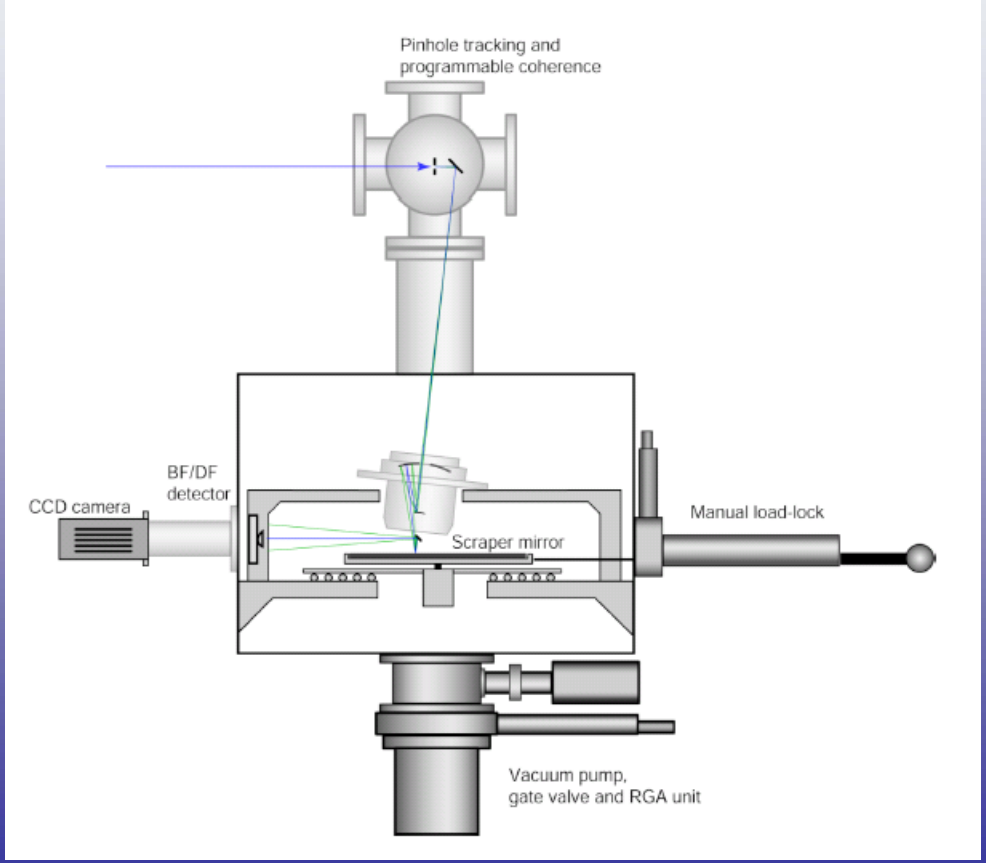


The path length from neighboring transparent zones to the focus differs by one optical wavelength

Experimental Configuration for first phase contrast Imaging



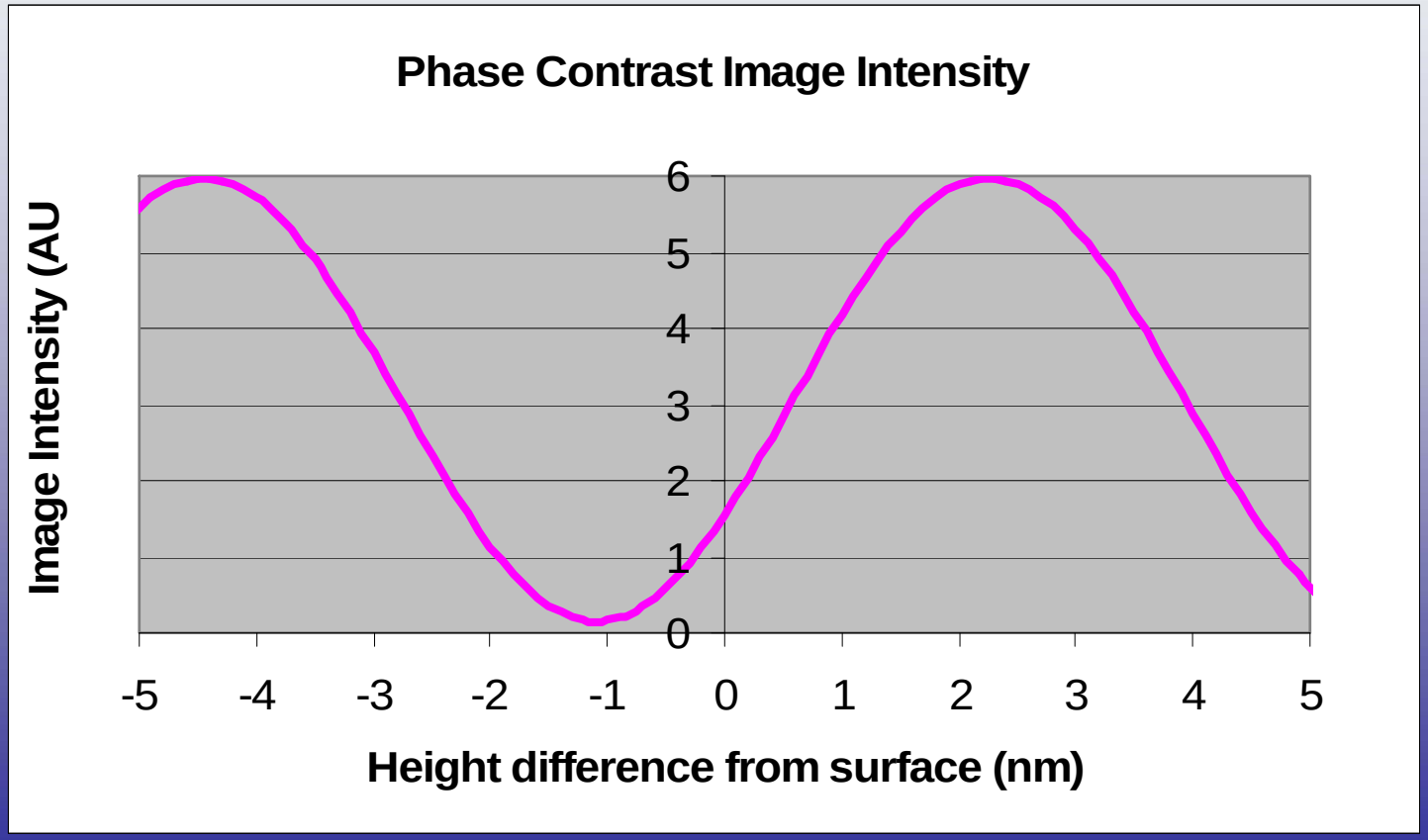
This phase contrast imaging will soon be incorporated into the Actinic Inspection and Defect Review system



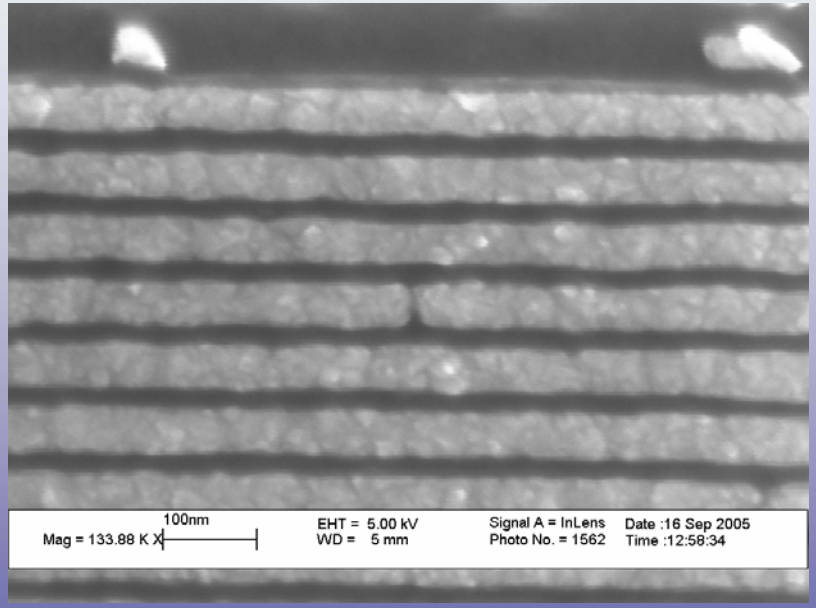
Anton Barty, Yanwei Liu, Eric Gullikson, John S. Taylor and Obert Wood, SPIE March 2005

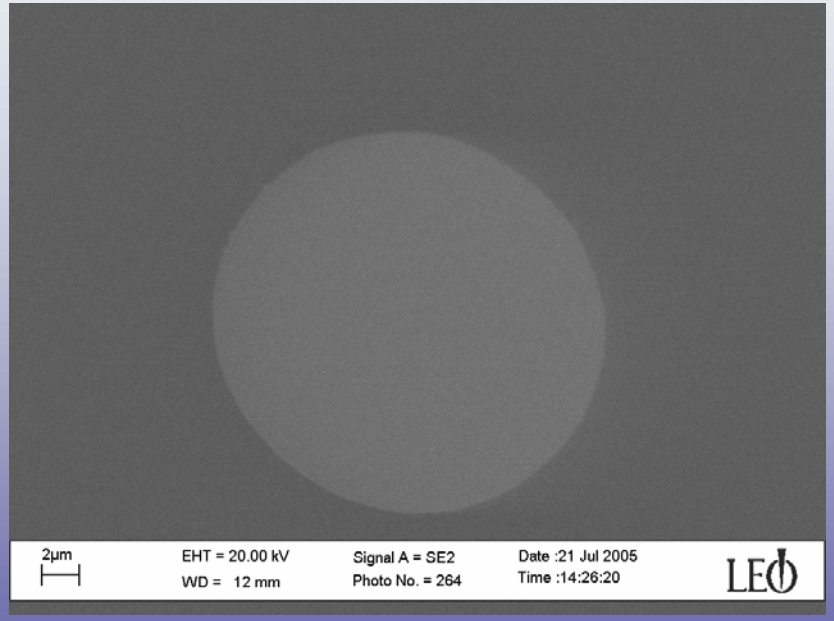
Image Contrast

Contrast for shifts of the reflecting “surface” for a 21 nm Mo phase plate ($\pi/4$ phase shift)



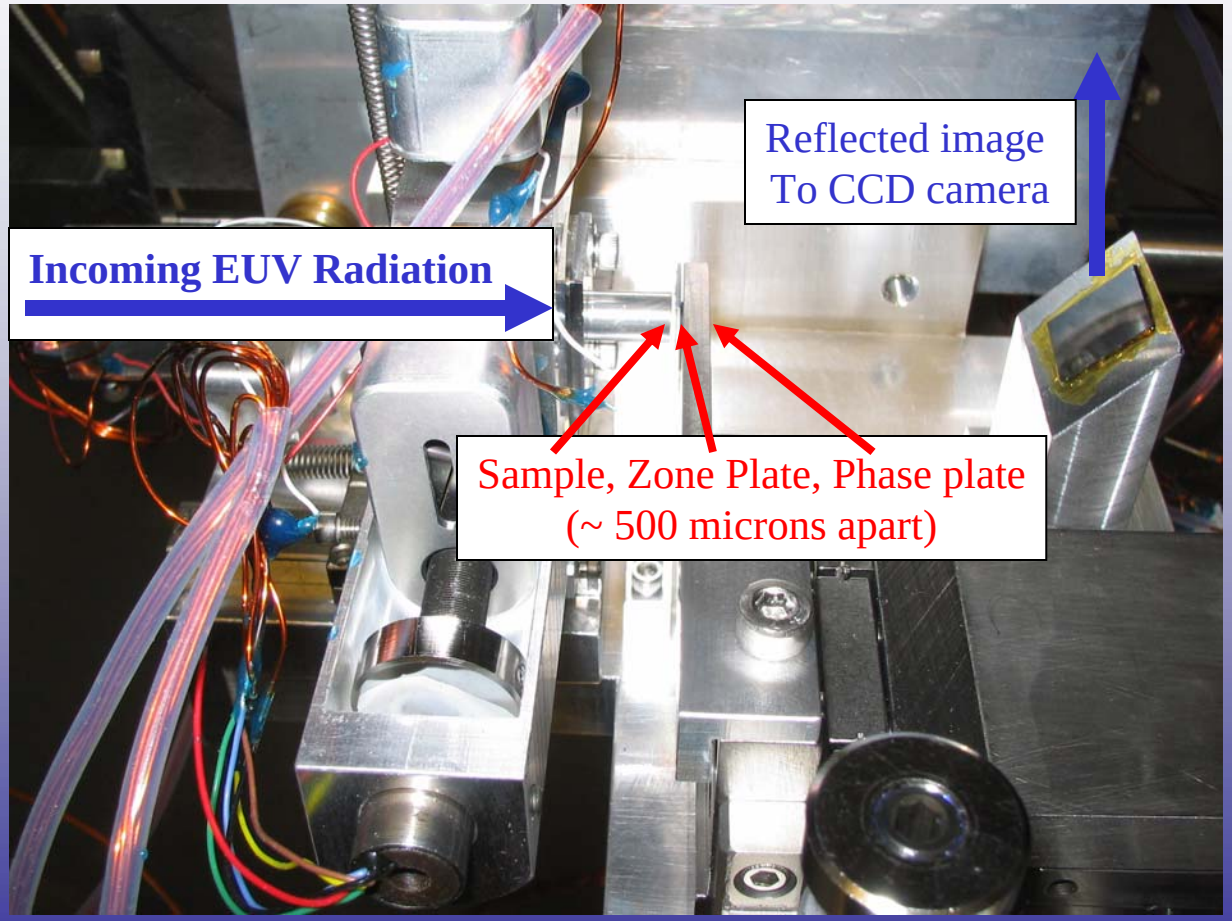
Zone Plate and Phase Plate





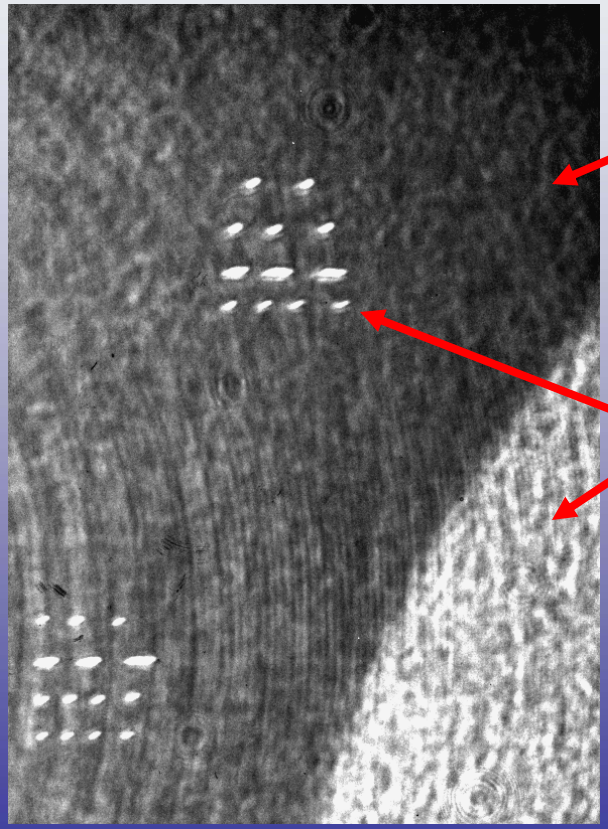
Both are fabricated on a SiN membrane

Experimental Configuration



First Images

Bright field image
Phase disk removed

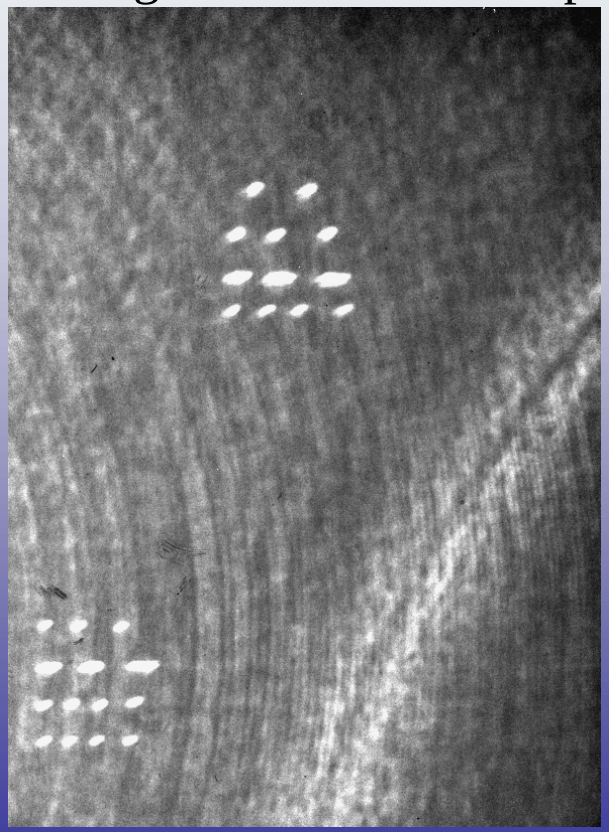


Molybdenum sample
Nominally 60 nm thick
70% transmission
2.2 radian phase shift

Clear regions of sample
(No molybdenum)

12 microns

Dark-field image
Absorbing disk in back focal plane



Conclusions

- **Zone plate microscopy provides high resolution imaging of EUV masks**
- **Using phase plates in the back focal plane of the objective lens can provide contrast mechanisms for measurement of the phase shift from defects on the mask**
- **The first high resolution EUV Zernike phase contrast images have been acquired**
- **Future work will include phase contrast mode in reflection from an EUV mask to directly measure the reflectivity and phase shift from defects**